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Habitat and Life History of Juvenile Hawaiian Pink Snapper, *Pristipomoides filamentosus*[1]

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ABSTRACT: Eteline snappers are an important component of commercial demersal fisheries in the central and western Pacific, but there is a substantial gap in the knowledge of their life histories, specifically the larval and juvenile stages. Juvenile pink snapper, *Pristipomoides filamentosus* (Valenciennes), ranging in size from 7 to 25 cm fork length, inhabit a nearly featureless plain offshore of Kāne'ohe Bay, O'ahu, at depths of 65–100 m. Bottom samples and underwater video footage showed the bottom to be uniformly composed of fine, silty sand with little relief. Conductivity-temperature-depth data indicate that an internal tide brings cold water over the bottom on a tidal basis. Telemetric studies show that juveniles undergo small-scale crepuscular migrations from deeper daytime locations to shallower nighttime locations but move relatively little during day and night periods. Analysis of length frequency distributions obtained over a 17-month period resulted in an estimate of the von Bertalanffy growth constant (K) of 0.21 yr^{-1}.

ETELINE SNAPPERS SUPPORT existing or developing fisheries throughout the central and western Pacific, where they are generally the most valuable component of the demersal fisheries. These fishes are prized for their high-quality flesh and large size. Adults concentrate near high-relief features on the deep slopes of Pacific islands and banks at depths of 100–400 m. Many aspects of the biology of the adults have been addressed: feeding (Kami 1973, J. D. Parrish 1987, Seki and Callahan 1988, Haight et al. 1993), growth (Ralston and Miyamoto 1983, Edwards 1985, Manooch 1987, Ralston and Williams 1988), reproduction (Everson 1984, Kikkawa 1984, Grimes 1987, Everson et al. 1989), and exploitable biomass (Polovina et al. 1985, Polovina and Ralston 1986, Polovina and Shomura 1990). Information on the larval and early juvenile stages, however, is lacking. Eteline snapper larvae are rarely encountered in ichthyoplankton collections, providing little biological information on presettlement fishes (Leis 1987, Clarke 1991). Aside from a preliminary investigation by Parrish in 1989, information on the juvenile stage of these fishes is nonexistent.

Parrish (1989) documented juvenile pink snappers, *Pristipomoides filamentosus* (Valenciennes), in a flat, featureless habitat very different from high topographic relief areas adults occupy. Juvenile eteline snappers have not been observed during submersible surveys of adult and subadult aggregations at natural (Ralston et al. 1986) and artificial (Moffitt et al. 1989) high-relief features. The use of a flat, featureless habitat as a nursery area is also very different from the situation reported for most other fishes, where the young utilize complex bottom habitats such as seagrass beds (Adams 1976, Heck and Weinstein 1989, Sogard and Able 1991), algal beds (Heck and Thoman 1981, Wilson et al. 1990), or natural and artificial reefs (Carlson and Straty 1981, Anderson et al. 1989, Connell and Jones 1991).

Understanding the biology and the ecological requirements of juvenile eteline snappers is necessary to appropriately manage both fish resources and their habitat throughout the Pacific region. This study expands on

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the work of Parrish (1989), providing greater detail of the physical features of the habitat and its spatial and temporal utilization by juvenile *P. filamentosus* in Hawai'i.

MATERIALS AND METHODS

Fishing Operations

A drifting 6-m boat equipped with a fish finder was used as the fishing platform for most of this study. All fish used in length frequency analysis were caught by rod and reel, fishing with light tackle. Terminal gear consisted of about 2 m of 7-kg monofilament line with a 0.1- to 0.2-kg lead weight on the bottom and four evenly spaced 30-cm-long 2- to 3-kg monofilament branch lines ending in circle hooks with a 5.5-mm gap. Strips of squid, *Loligo opalescens* Berry, were used as bait. Lines were fished with leads on or near the substrate. Depth of capture and fork length (FL) to the nearest 1 mm were recorded for all pink snapper taken. Prey items regurgitated from pink snapper upon landing were noted, but no gut analysis was conducted. Whenever possible, fish were returned to the ocean after we vented excess gas from their swim bladder with a hypodermic needle and repositioned the stomach when everted. Moribund fish were iced and returned to the laboratory for other use (e.g., weighing and otolith studies). We fished only during daylight hours, between 0900 and 1600 hours.

Survey of Sites

Thirteen exploratory fishing trips were conducted around O'ahu between 2 October and 9 November 1989 to identify a site that would yield enough juvenile pink snapper for a temporal analysis. Survey effort focused on leeward O'ahu, where better weather conditions permitted more regular sampling. Depths between 50 and 150 m were fished over 40% of the island's coastline (Figure 1). Windward sites where fish had previously been found were also included (Parrish 1989).

Temporal Sampling

Length frequency samples were collected monthly between October 1989 and February 1991. Intervals between samples were usually 4–6 weeks, with one gap of 9 weeks caused by poor weather conditions. Obtaining each sample required between one and five fishing days and ended after 1 week or when about 100 fish had been caught.

An estimate of the von Bertalanffy growth parameter, K, was obtained using the ELEFAN computer program (Gayanilo et al. 1989), with L_∞ restricted to 78 cm as estimated by Ralston and Miyamoto (1983). The length-weight relationship was calculated using the SAS nonlinear regression program (NLIN).

Habitat Description

Environmental conditions of the juvenile snapper habitat off Kāne'ohe Bay were studied on a *Townsend Cromwell* cruise (TC-90-02) in February 1990. Three transect lines were established perpendicular to the depth contours off the southern, central, and northern portions of the bay (Figure 1). Bottom grabs and conductivity-temperature-depth (CTD) casts were taken at five depths (45, 60, 75, 90, and 105 m) along each transect.

Sediment samples were frozen when collected, then oven-dried at 50–60°C, stored in a desiccator until cooled to room temperature, and weighed to the nearest 0.1 g. The samples were washed through a series of three sieves with mesh sizes of 2, 0.42, and 0.06 mm. The material remaining on each of the screens was redried and weighed. Based on the classifications established by Wentworth (1922), the materials collected on the 2-mm sieve are termed "granules or larger," those on the 0.42-mm sieve are "medium to coarse sand," those on the 0.06-mm sieve are "fine to medium sand," and the material lost through the last sieve (calculated by subtracting the weight of sediment collected on the three sieves from the original weight) is termed "mud." A sand-mud ratio was calculated by dividing the combined weight of the

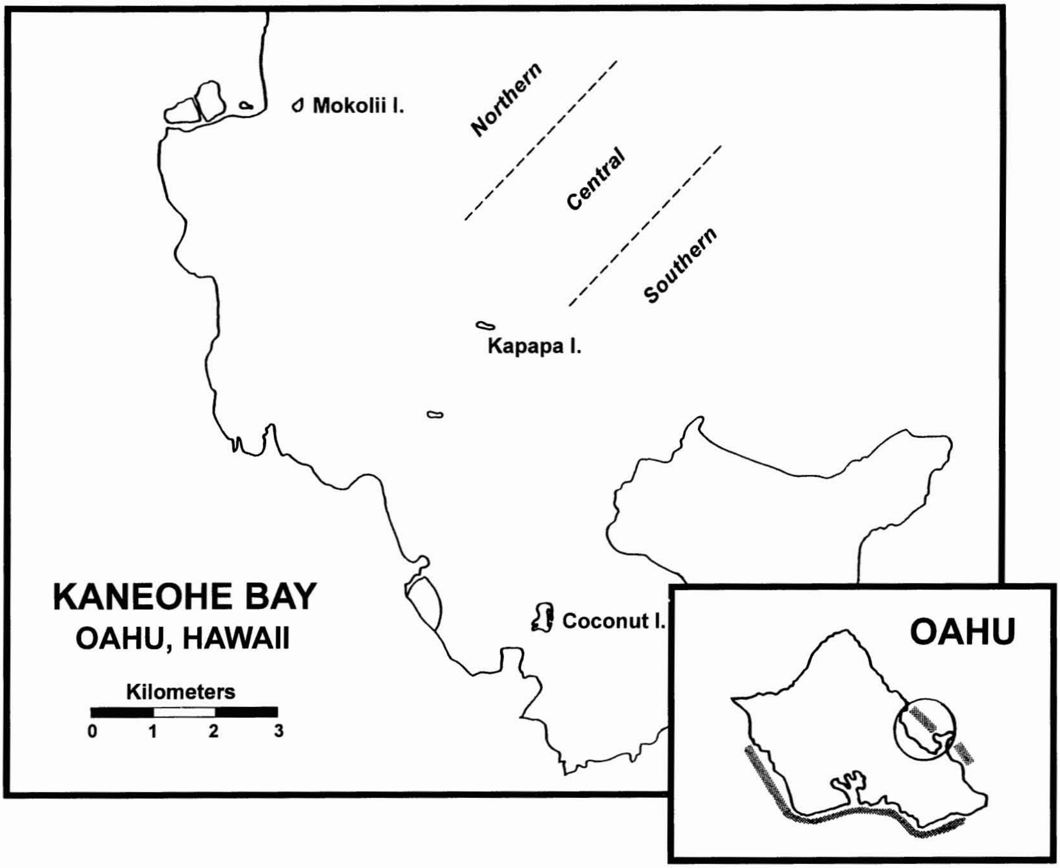

FIGURE 1. O'ahu and Kāne'ohe Bay (shaded areas on the O'ahu map represent coastline fished in the initial survey).

two sand categories by the weight of the mud for each sample. Visual documentation of the bottom type and associated fauna was obtained from eight baited video camera drops conducted between October 1990 and January 1991.

Temperature profiles were generated from the CTD data collected at the same times and sites as the bottom grabs. An additional series of CTD data was taken for a 24-hr period along the northern transect line. In this series, CTD data were collected for each depth on the transect every 1–2 hr. Temperature profiles were also obtained in December 1989 ($n = 3$), November 1990 ($n = 16$), and December 1990 ($n = 6$).

Telemetry

Acoustic tags were implanted in two hooked pink snappers using a subsurface tagging method developed in this study and reported in Parrish and Moffitt (1992). Within 25 min, each fish was captured, tagged, and released near the point of capture. After release, each fish was intermittently tracked over a 5-day period (the approximate life of the tag's battery) by a surface vessel with a directional hydrophone. Time, bottom depth, and location were recorded every $\frac{1}{2}$–1 hr during tracking. The tags were ca. 8 by 30 mm cylinders with a specific acoustic frequency between 65 and

75 kHz depending on the tag. On the first tracking, positions were calculated from visual and radar sightings of shoreline features. On the second tracking, positions were obtained from a portable Global Positioning System (GPS) unit.

RESULTS

Sites Surveyed

A total of 66 juvenile pink snapper was captured at only two sites during this survey. Four specimens were caught on leeward O'ahu, off Honolulu Harbor, at depths of 63–100 m during 5 days of fishing. The remaining 62 specimens were taken at similar depths during 3 days of windward coast fishing off Kāne'ohe Bay. The temporal and habitat evaluation focused on the high snapper yield of the Kāne'ohe site.

Temporal Sampling

A total of 1047 juvenile pink snapper ranging from 8 to 25 cm FL was caught in the northern and central portions of the Kāne'ohe Bay site at depths of 60–100 m during the monthly sampling. No pink snapper were caught in the southern portion of the study site. Fishing frequently extended beyond the 60–100 m targeted depth range, but no juvenile pink snapper were captured outside the target depths. Catches of juvenile pink snapper on the "highest" of the fishing lines' four hooks (about 2 m off the bottom) were rare, suggesting that these fish have a close association with the bottom. Large, obvious regurgitated prey included postlarval fishes (gobies, synodontids, and *Lutjanus kasmira* [Forsskal]), small cephalopods, and portunid crabs.

Fish length was not correlated with depth of capture ($R^2 = 0.035$), indicating no obvious stratification of size by depth. ELEFAN analysis of the 13 length frequency distributions (Figure 2) identified two modes in the October to February data for both 1989–1990 and 1990–1991, indicating the presence of two year classes on the nursery grounds during those months. The ELEFAN estimation of the von Bertalanffy growth constant (K), with a preselected L_∞ of 78 cm, was $K = 0.21$ yr^{-1}.

Weight (W) in grams was recorded for 125 individuals ranging in FL from 8.0 to 20.8 cm, and the data were used to determine the length-weight relationship ($W = a\mathrm{FL}^b$). Values obtained for the parameters (with the ranges of the 95% confidence intervals) were $a = 0.018$ (0.012–0.025) and $b = 2.99$ (2.87–3.12).

Habitat Description

The sieve analysis of bottom grabs ($n = 15$) showed that sediments at 45 m consisted mostly of coarse sand and larger materials (Table 1). At greater depths, where the snappers inhabit, the sediments were dominated by fine sand and mud in almost all samples.

Review of the video camera tapes, and observations from the depth finder during fishing operations, confirmed the lack of vertical relief in the area. The bottom appeared to be entirely soft, with many invertebrate burrows and occasional shallow depressions that may have been made by either dasyatid rays or portunid crabs. Species recorded by the camera over this habitat include juvenile pink snapper; white crab, *Portunus sanguinolentus* (Herbst); dasyatid ray; subadult amberjack, *Seriola dumerili* (Risso); spiny puffer, *Torquigener* sp.; sharp-nosed puffer, *Canthigaster rivulata* (Schlegal); and carcharhinid sharks. On two occasions, when a strong current was present, the camera frame was dragged across the bottom, passing derelict crab traps. In the vicinity of the traps, species composition changed dramatically, to one of *Chaetodon miliaris* Quoy & Gaimard, *Heniochus diphreutes* Jordan, *Lutjanus kasmira, Priacanthus* sp., *Parupeneus chrysonemus* (Jordan & Evermann), and *Canthigaster coronata* (Vaillant & Sauvage). No pink snapper were observed near the traps.

Analysis of CTD temperature data showed evidence of an internal tide with a semidiurnal periodicity that provides an influx of cold water over the bottom on the juvenile pink snapper nursery grounds during high

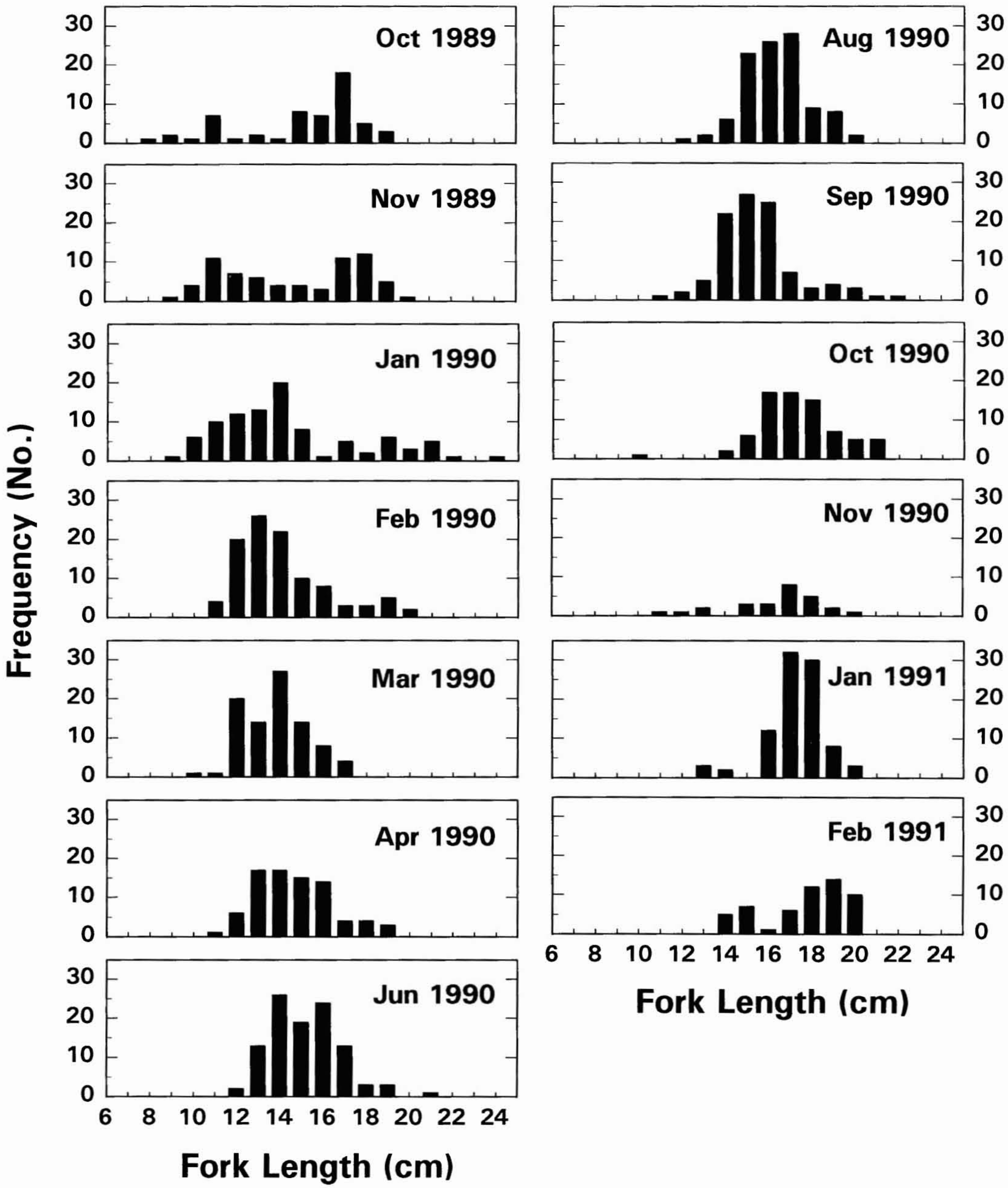

FIGURE 2. Length frequency distribution of juvenile pink snapper by month.

tide. The presence of this tide is best shown with the 24-hr CTD casts taken along the north transect line (Figure 3). Surface temperature at all sites was about 23.0–23.5°C, gradually declining to about 22.0–22.5°C at 90 m at low tide. During high tide, temperature in the upper 70 m remained unchanged, while temperature from 70 m to the bottom declined rapidly to a low of about 20.5–21.0°C on the bottom. This internal tidal

TABLE 1

SEDIMENT SIZE BY DEPTH ON TRANSECTS TAKEN ON JUVENILE PINK SNAPPER NURSERY GROUNDS

		PARTICLE SIZE (% of total)				
TRANSECT	DEPTH (m)	≥GRANULE	COARSE SAND	FINE SAND	MUD	SAND/MUD RATIO
Southern	45	55.4	37.0	6.6	1.0	41.9
	60	3.1	16.6	74.8	5.5	16.5
	75	6.0	23.9	43.3	26.9	2.5
	90	3.2	14.3	36.7	45.8	1.1
	105	10.3	35.3	39.1	15.2	4.9
Central	45	46.7	43.4	7.3	2.6	19.4
	60	30.6	48.7	16.6	4.0	16.2
	75	0.2	1.6	44.3	54.0	0.8
	90	1.4	5.3	41.1	52.2	0.9
	105	7.4	13.4	44.3	34.9	1.7
Northern	45	29.8	18.8	46.5	4.9	13.3
	60	0.7	6.1	78.0	15.1	5.6
	75	1.0	2.0	50.1	46.9	1.1
	90	0.03	0.5	41.7	57.8	0.7
	105	0.4	1.1	52.0	46.5	1.1

feature with a temperature inflection at 60–80 m was observed to some extent at all sample depths except the shallowest (45 m) and was observed on all sampling days, suggesting that it is a persistent phenomenon.

Telemetry

Two juvenile pink snappers (each 19 cm FL) were successfully tagged and tracked over a period of 5–6 days (Table 2). Both fish moved similarly from deeper daytime positions to shallower nighttime locations. The migration was not linked to the temperature fluctuation caused by the internal tide described above but was crepuscular in periodicity. Each fish exhibited discrete day and night depths and positions, migrating between the two positions rapidly (within 30–40 min) at dawn and dusk. Day ranges were double or more than double the area of the night ranges for both fish, indicating greater daytime activity. Recorded day and night positions for the first fish contained a small degree of overlap; however, the lack of overlap in the depths recorded for these positions indicate that this was an artifact of the poor positioning method used. With the better positions obtained for the second tagged fish, we were able to observe its return to capture position. It was caught at a depth of 72 m, the GPS position was recorded, and then it was released (after processing during a drift) where the depth was 61 m (about 300 m from the capture location). The fish gradually moved deeper over the next 2 hr, arriving at its capture location, where it remained until dusk. Video records of the day and night positions of the second fish revealed no discernable difference in bottom features, though the fish are quite obviously able to recognize particular locations on the bottom.

DISCUSSION

The results of this study can now be used as a framework in which the early life history of juvenile pink snapper off Kāne'ohe Bay can be described. Juveniles first arrive at a size of about 7–10 cm FL (the smallest captured was 7.3 cm FL) in October or November. Although it is not known whether juveniles are just settling after a long pelagic stage or immigrating from another benthic habitat, juveniles of this size or smaller have not been reported from other benthic habitats, either deeper or shallower. Leis (1987)

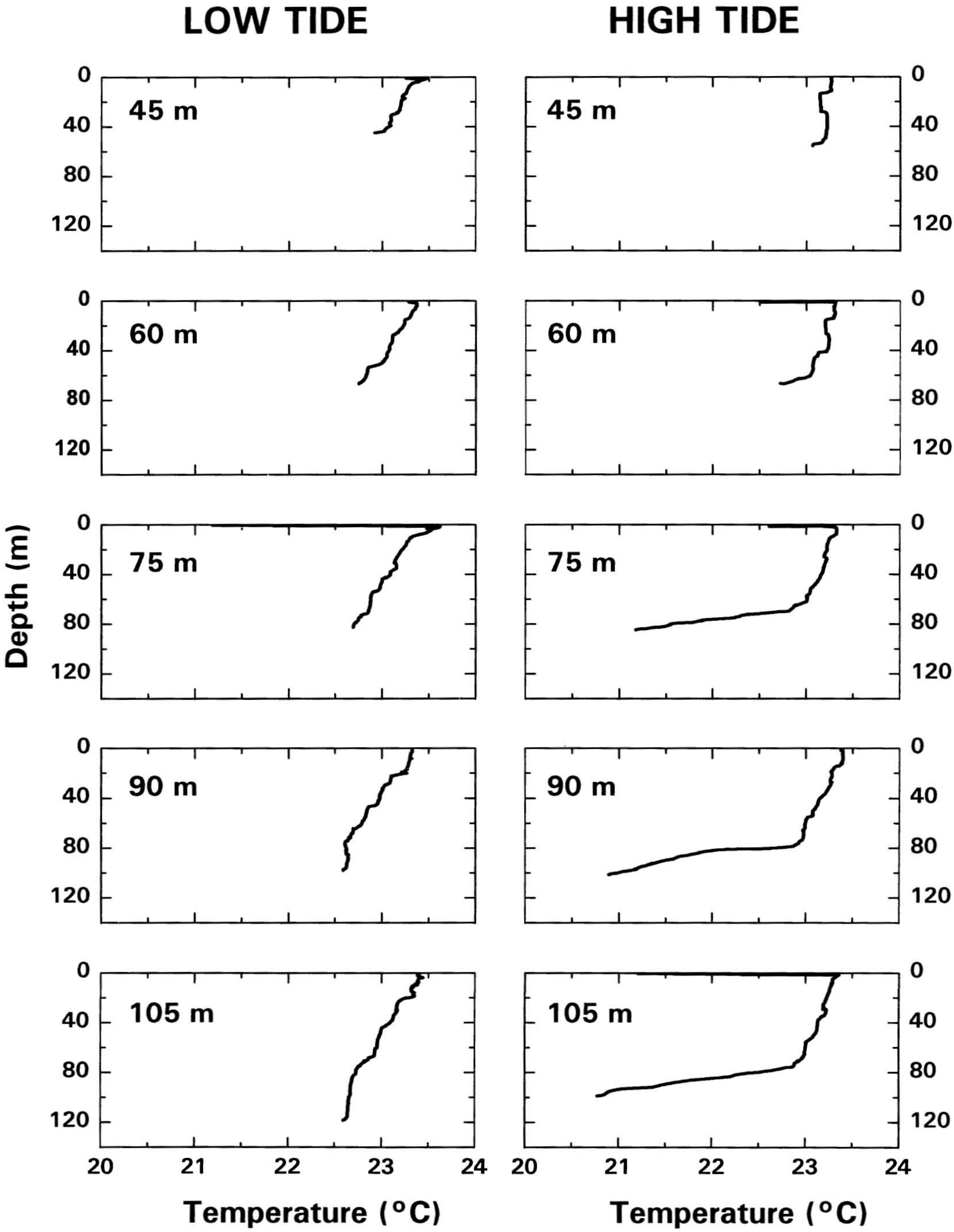

FIGURE 3. Temperature profiles at high and low tides.

TABLE 2

RESULTS OF TELEMETRY

PARAMETERS	FISH 1	FISH 2
Dates tracked	4–8 December 1989	13–18 September 1990
Daytime depth range (m)	84–87	71–73
Nighttime depth range (m)	74–77	65–67
Area of daytime positions (km^2)	0.40	0.06
Area of nighttime positions (km^2)	0.20	0.02

reported a pelagic juvenile of the congeneric *Pristipomoides sieboldii* (Bleeker) of 5.0 cm length, suggesting that our smallest juveniles off Kāne'ohe Bay may indeed have recently settled from their pelagic stage. Juvenile pink snapper remain on the nursery grounds for a period of 6–7 months or until they reach 18–20 cm FL (although some individuals as large as 25 cm FL remain in the area). After leaving the flat, featureless nursery grounds, the juveniles appear to concentrate around high-relief features in deeper water. A documented example is an artificial reef at 150 m off leeward O'ahu, where pink snappers ($\geq$20 cm FL) are routinely caught by State of Hawai'i Division of Aquatic Resources personnel (Okamoto 1993).

The estimate of growth based on length frequency distributions ($K = 0.21$ yr^{-1}) falls within the range of values (0.10–0.25) reported for species of Lutjanidae (Manooch 1987). It is supported by preliminary results of otolith examination for these juvenile pink snapper, indicating ages of about 180 days for a 10.5 cm FL fish and about 350 days for an 18.5 cm FL fish (DeMartini et al. 1994).

Recruitment to this nursery ground appears to vary considerably between years. In February 1990, the 1989 year class (FL $\leq$ 16 cm) was much more abundant than that from 1988 (FL $\geq$ 17 cm); in February 1991, the 1990 year class was much less abundant than that from 1989. Differences in catch per unit effort obtained during the two sampling periods (103 fish on 1 day in February 1990 versus 55 fish on 2 days in February 1991) furnish crude supporting evidence for this variability. Currently, we have no way of determining whether the 1989 year class was particularly strong or the 1990 (and possibly 1988) year class was particularly weak.

The nursery habitat used by the juvenile pink snapper appears to be very different from that described for other juvenile fishes. Most authors suggest that highly complex substrates (e.g., coral reefs, artificial reefs, seagrass, and algal beds) reduce predation by providing protective shelter (Adams 1976, Heck and Thoman 1981, Wilson et al. 1990, Connell and Jones 1991) for juveniles of various species. Juvenile pink snapper at the Kāne'ohe Bay nursery may achieve comparable protection from predation by utilizing flat, featureless areas where predators are absent. At the depths involved here, high-level predators (adult snappers, amberjacks [Okamoto 1993], and other jacks) concentrate around high-relief structures and do not occur in large numbers over featureless bottoms (Ralston et al. 1986, Moffitt et al. 1989).

It may not be merely coincidental that 60 m is the shallowest depth at which juvenile pink snapper have been observed off Kāne'ohe Bay and is also the shallowest depth where effects of the internal tide were recorded. Studies of internal waves near the surface of the ocean indicate that these phenomena assist in shoreward transport of larval fish and crustaceans (Kingsford and Choat 1986, Shanks and Wright 1987, Shanks 1988). Although similar studies have not been conducted on subsurface internal waves, such as the internal tide described here, it is possible that a similar process may occur. The internal tides may assist in shoreward transport of postlarval pink snapper. Examination of the sand/mud ratios (Table

2) indicates a strong discontinuity in the transition from larger to smaller particle sizes at the 60-m depth. A trend of higher sand/mud ratios in the southern versus northern and central portions of the study area for each depth sampled may be associated with the lack of juvenile pink snapper in the southern area. Interrelationships between the internal tide, sediment particle size, and occurrence of juvenile pink snapper currently are not understood, but the transition in all three factors at 60 m on the nursery grounds raises intriguing questions about the processes involved.

Telemetry suggests that juvenile pink snapper, like the adults (Moffitt 1980), migrate crepuscularly. Our tagged fish moved as if they were able to recognize bottom locations and return to their habitual sites, both on a routine daily basis and when artificially displaced from their initial location (i.e., our second tagged fish moved between capture and release). The benefit obtained from these short-range daily migrations is not known. Day and night positions for both tagged fish occurred within the range of depths where pink snapper are routinely captured during the day. Thus, night positions of our tagged fish were probably utilized by other juvenile pink snapper during the day and day positions utilized by yet others at night.

This study has examined a relatively concentrated, isolated, and persistent population of juvenile pink snapper occupying a uniform featureless habitat in northern Kāne'ohe Bay. Successive year classes were observed to use the same habitat, with individual fish apparently making only small diel movements. Observations, measurements, and collections were made on some characteristics of the habitat that may affect its use by juvenile pink snapper. However, this work is descriptive and is not compared with that on other pink snapper nursery grounds. Thus, we are unable to attach the importance of any of these characteristics to juvenile snapper with any confidence. Future research should be directed toward locating other pink snapper nursery grounds and comparing those habitats with that described above as well as to a more intensive study of the Kāne'ohe Bay nursery ground. After more research, we should be able to determine the relevance of nursery grounds for eteline snappers throughout the Indo-Pacific region. The low-relief shelf areas used by juveniles of this and perhaps other eteline species could be a limited resource because of the steep slopes of most oceanic islands. Consequently, management and protection of these habitats may be important. Such protection appears contrary to conventional wisdom that expounds the benefits in terms of productivity of creation of artificial structures on just such low-relief areas.

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